

## Comment on "Temperature dependence of the second magnetization peak in a deoxygenated $\text{YBa}_2\text{Cu}_3\text{O}_{6.65}$ single crystal"

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Measuring magnetic relaxation and hysteresis of a deoxygenated Y-123 single crystal with  $T_c = 62.5$  K, Salem-Sugui, Jr. and coworkers [Phys. Rev. B **60**, 102 (1999)] analyze the fishtail effect (FE) in a broad temperature range, 1.8 to 60 K. They interpret their experimental data at temperatures above 5 K as a crossover from elastic to plastic creep, which causes the fishtail peak. At low temperatures, below 5 K, they see evidence for plastic creep even below the FE maximum. Their experiment can be, however, alternatively explained in terms of a thermally activated flux creep [Perkins *et al.*, Phys. Rev. B **51**, 8513 (1995)] affected at low temperatures by self-field effects.

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In the recent article of Salem-Sugui, Jr. *et al.*<sup>1</sup> the authors study the magnetic behavior of a deoxygenated  $\text{YBa}_2\text{Cu}_3\text{O}_{6.65}$  single crystal. Due to the significant oxygen deficiency the critical temperature is only 62.5 K and the irreversibility field is so low that the field range for observation of the fishtail effect (FE) lies within accessible fields up to the lowest temperatures. In principle, such a type of experiment is very useful, allowing for investigation of the FE character in a broad temperature range. The relatively high oxygen deficiency provides a dense structure of pins assuring a fully developed FE peak.<sup>2,3</sup>

The central result of Salem-Sugui, Jr. *et al.* is the relaxation study made at the fields around the FE maximum. Due to the relatively low fields at which the FE appears in this sample, the FE peak always lies close to the central peak. The pinning regime within the field range of the central peak is, however, strongly affected by self-fields<sup>4-6</sup> and the peak has quite a different temperature dependence than the FE peak. The position of the central peak changes only slightly with temperature but its width (related also to the full penetration field  $H_p$ ) and height strongly increase with decreasing temperature. As a result, the central peak at low temperatures usually dominates the shape of the magnetization hysteresis loop (MHL) in the whole experimentally accessible field range, or at least strongly overlaps with high-field details of the MHL. The descending field branches of the MHL's shown in the left inset of Fig. 1 indicate that this is also the case of the studied sample.

Salem-Sugui, Jr. *et al.* started their measurements from the zero-field-cooled state. Thus the central peak was suppressed on the ascending field branch; however, stray fields exceed into the field range of the second peak, especially at temperatures below 5 K, where the authors report on a change in pinning mechanism.

Perkins *et al.*<sup>4,7</sup> showed that the relaxation rate  $S = -\partial \ln|M|/\partial \ln t$  is in any point of the MHL equal up to an additive constant to the logarithmic susceptibility,  $\partial \ln|M|/\partial \ln|B| \doteq \partial M/\partial B \cdot B/M$ . This means that the logarithmic relaxation rate has its extremes in the vicinity of inflec-

tion points on the MHL. This property was observed on a large variety of samples exhibiting different MHL shapes,<sup>8,9</sup> and the work of Salem-Sugui, Jr. *et al.* gives further evidence of this behavior (Figs. 2,3). The sensitivity of the second peak position to the relaxation state observed by the authors at high temperatures is just one of the consequences of the above-mentioned scheme: On the separately standing FE peak,  $S$  has its minimum on the low-field slope and continuously increases with field in the region of the peak maximum (see the data at 7 K, Fig. 3). Because of the higher relaxation rate at the top of the FE peak, the magnetic moment relaxes there faster than on the peak slope. Therefore, the peak shifts during the relaxation process towards lower relaxation rates, i.e., towards lower fields [Fig. 2(c)]. On the contrary, at low temperatures, due to the enhanced contribution of self-fields (central peak), the MHL has a broad plateau at low fields, connected on its high-field end with the top of the second peak. As  $S$  is nearly constant on the plateau, the plateau, including the shallow top of the FE peak, does not shift during relaxation [Fig. 2(d)]. The observed change in the character of  $S(B)$  at low temperatures can be therefore explained by a gradual overlapping of the second peak by the first one.<sup>4,7</sup>

The above arguments can be verified on the sample with a properly chosen oxygen deficiency, where the fishtail peak would be, at low temperatures, still observable in the available field range but would be better separated from the central peak.

My final comment concerns the opinion of the authors taken from the work of Abulafia *et al.*<sup>10</sup> that the character of the second peak at high temperatures is "dynamic" [in contrast to the static one governed by  $J_c(B)$  dependence]. Though the MHL in magnetic experiments always has a dynamic character manifested by its dependence on the effective field sweep rate, the value of  $J_c$  always stands in the background of the measured (sub)critical state, as a scale of the observed  $J$ . Both the static and dynamic characteristics play an equally important role in the MHL formation and it is difficult to separate them.

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## Reply to "Comment on 'Temperature dependence of the second magnetization peak in a deoxygenated YBa<sub>2</sub>Cu<sub>3</sub>O<sub>6.65</sub> single crystal' "

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Using magnetic hysteresis loops obtained at 3.3 K, together with magnetic relaxation measurements, we demonstrate that the location of the central magnetization peak  $H'$  is well resolved, and occurs well below the second peak  $H_p$ .

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In his Comment,<sup>1</sup> Jirsa claims that the fishtail effect (FE) reported at temperatures below 5 K in the magnetic hysteresis loops (MHL) of Ref. 2 appears flat (i.e., independent of  $H$ ), due to the close proximity between the first or central magnetization peak (centered at  $H'$ ) and the second peak (centered at  $H_p > H'$ ). Since the vortex dynamics in the vicinity of  $H'$  is affected by self-fields, Jirsa contends that self-fields can explain the fact that  $H_p$  does not shift during relaxation at low temperatures, in contrast with observations at high temperatures. Jirsa prefers an alternative explanation of our experimental results, based on a vortex dynamics study by Perkins *et al.*<sup>3</sup> In Ref. 3, the authors show that the normalized creep rate,  $S = d(\ln|M|)/d(\ln t)$ , is equal to  $d(\ln|M|)/d(\ln|B|)$  plus a constant, where  $B$  is the local field. By plotting our high-temperature MHL data as  $S$  vs  $B$ , we highlight the changes in the vortex dynamics, which can be ascertained from the slope of the MHL near the FE. We note that such an analysis is independent of any models of pinning mechanisms. We thank Jirsa for pointing out this possibility in his Comment. On the other hand, it is important to

emphasize that the study of Ref. 3 is only performed on MHL exhibiting the fishtail effect at higher temperatures. Perkins *et al.* observed that at low temperatures the creep rate,  $S$ , hardly varies from a universal value of  $-0.03$ . Consequently, little information about vortex dynamics can be obtained from the analysis.

In this Reply we find that at low temperatures there is enough of a variation of  $S$  with the magnetic field to resolve the existence of the first (central) and second peaks. This is done by plotting  $S$  vs  $H$ , as in Ref. 3. It is worth mentioning that the central peak is associated with entering the superconducting mixed state phase,<sup>4,5</sup> while the second peak is the fishtail. We also mention that we agree with Jirsa about the importance of self-field effects in the vicinity of the central peak,  $H'$ . However, we point out that the author's claims are based on the first inset of Fig. 1 in Ref. 2, which shows several MHL obtained up to 9 T. In this small plot, it is somewhat difficult to resolve the values of  $H'$  and  $H_p$ . To clarify our technique, we present in Fig. 1, below, a larger view of the MHL curve obtained at 3.3 K. At this temperature we find that (i)  $H_p$  is not time dependent, and (ii) the fishtail effect is well resolved. The figure clearly shows that  $H'$  and  $H_p$  are separated by  $\sim 1.5$  T. To demonstrate the independence of the two peak features, we also plot  $S = d(\ln|M|)/d(\ln t)$ , as obtained over 4500 sec from magnetic relaxation measurements, performed at 3.3 K for several values of  $H$ . This plot reveals that relaxation near and above  $H_p$  is essentially uncorrelated with relaxation at fields near  $H'$ . It is important to observe that the values of  $S$  in Fig. 1 are close to the universal value  $S = -0.03$ , mentioned above.

In conclusion, we learn from Jirsa's Comment that the analysis of Ref. 3 can explain our MHL data. When applied to MHL obtained at 3.3 K, this same analysis shows that self-field effects are not significant in the vicinity of the fishtail. Additional experiments on samples with doping variations can shed further light on this issue.

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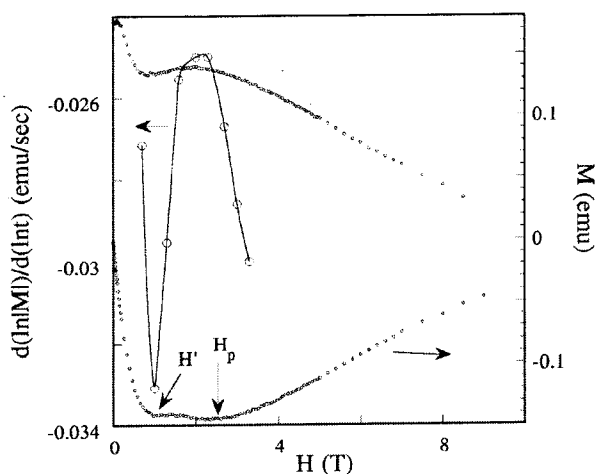


FIG. 1. Magnetic hysteresis loop at 3.3 K plotted with the respective  $d \ln|M|/d \ln t$  values obtained for several values of  $H$ .

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